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CERTIFICATION

I, the below named translator, hereby declare that: my name and post office address are as stated below; that I am knowledgeable in the English and German languages, and that I believe that the attached text is a true and complete translation of PCT/EP2004/053355, filed with the European Patent Office on December 8, 2004.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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CONTROLLING OF A DIRECT-CURRENT MOTOR

The present invention relates to a method for controlling a brushless direct-current motor and an AC/DC inverter suitable for carrying out the method.

The stator of such a motor generates a rotating magnetic field in which the magnets of the rotor attempt to align themselves and thereby drive a rotation of the rotor. In order to achieve the highest possible electrical efficiency of such a motor, it would be desirable to act upon three windings of the stator with sinusoidal currents, each phase-shifted by a third of a period with respect to one another. Since the rotational speed of the motor depends on the frequency of the currents, it must be possible to provide these currents with variable frequencies. In order to provide driving currents with arbitrarily selectable frequency, AC/DC inverters are usually used, which act upon the windings of the motor in pulsed mode with a fixed supply voltage, where the repetition frequency of the switch is substantially higher than the rotational frequency. The better a sinusoidal profile of the supply voltage is to be approximated with this type of AC/DC inverter, the higher the required frequency of the switching processes in the switches of the AC/DC inverter. The power loss of the switches increases with the switching frequency. If the switching frequency is too high, this can therefore result in overheating and destruction of the switch. The attainable efficiency of the motor is a compromise between the desire for sinusoidal supply currents for the motor windings on the one hand and the need for a low switching frequency and corresponding low losses in the AC/DC inverter on the other hand.

A widely used control method uses six periodically alternating switching states each having a duration of one sixth of a period wherein each winding is currentless respectively during one state, then current flows in a first direction for two states, then the winding is currentless for another state and finally current flows in the opposite direction for two further states and the currents of the three windings are each phase-shifted by a third of a period. This scheme is simple to control but one of the three windings of the motor is continuously currentless so that this does not contribute to forming the torque of the motor. The winding and the strengths of the currents flowing therein must therefore be designed so that the two windings through which current flows are sufficient to deliver a required torque. A control method whereby current could flow through all three windings at all times would allow the number of turns of the windings to be reduced for the same torque and thereby save not only costs, weight and size but also reduce ohmic losses and improve the efficiency.

[004] It is the object of the invention to provide such an improved control method.

[005] The object is achieved by a method for controlling a three-phase direct-current motor wherein three first switching states are cyclically repeated, wherein in each of the first three switching states one other of the three phases is periodically switched over between a first and a second input voltage whereas the two other phases are continuously connected to the first input voltage. Whilst one phase is connected to the second input voltage, a current flows in each case in a series circuit through this one phase and the two other phases parallel to one another so that all

three phases carry current and contribute to the torque of the motor.

[006] Uniform running of the motor is achieved if respectively one second switching state is inserted between two first switching states, in which one of the three phases is periodically switched over between the first and the second input voltage whereas the two other phases are continuously connected to the second input voltage. Here also, current flows through all three phases if one phase is switched to the first input voltage.

[007] A continuously concentrically running space vector is obtained if in every second switching state that phase is periodically switched over which is periodically switched over neither in the preceding nor in the following first switching state.

[008] For a uniform motor power it is further desirable that the fraction of the time in which, in every first switching state, the periodically switched-over phase is connected to the second input voltage from the duration of this first switching state is equal to the fraction of the time in which the periodically switched-over phase is connected to the first input voltage from the duration of each second switching state.

[009] This time fraction is appropriately regulated in every first and/or second switching state proportionally to the load of the direct-current motor.

[010] If an AC/DC inverter is used for controlling the direct-current motor, which for each phase of the motor, has a first switch placed between a terminal carrying the first

input voltage and the relevant motor phase and a second switch placed between the relevant motor phase and a second terminal carrying the second input voltage, in every first switching state, the first switch of the periodically switched-over phase can remain open whilst the second switch of this phase is periodically switched over. Thus, no switching losses occur in the first switch. Accordingly, in every second switching state, the second switch of the periodically switched-over phase can remain open whilst the first switch of this phase is periodically switched over.

[011] An AC/DC inverter according to the invention is fitted with a control circuit for controlling its switches according to a method as defined above.

[012] Further features and advantages of the invention are obtained from the following description of exemplary embodiments with reference to the appended figures. In the figures:

[013] Figure 1 is a block diagram of an AC/DC inverter which can be used to carry out the present invention;

[014] Figure 2 is a time diagram illustrating the states of the switches of the AC/DC inverter as well as the voltages and current flow directions in the phases of the motor for the various states of the method according to the invention; and

[015] Figure 3 is the simulated time profile of the current signal of one phase of an electric motor controlled according to the invention.

[016] The AC/DC inverter shown in Fig. 1 comprises six switches SU1, SV1, SW1, SU2, SV2, SW2 of which the switches SU1, SV1, SW1 are in each case arranged between a positive supply terminal (+) and a phase U, V or W of a three-phase brushless direct-current motor M and the switches SU2, SV2, SW2 are each arranged between one of these three phases and a negative supply terminal (-). The switches can be IGBTs with a suppressor diode connected in parallel in a manner known per se.

[017] A control circuit C generates control sequences for opening and closing the switches SU1 to SW2 depending on two input signals which designate a desired rotational frequency of the magnetic field in the direct-current motor M or a desired power of the motor.

[018] The control circuit C cyclically repeats a sequence of six switching states. In the first switching state, designated as a in Fig. 2, the switches SU1, SW1 connected to the positive terminal are closed and the respectively complementary switches SU2, SW2 are open so that the positive supply potential is applied to the phases U, W. The switch SV1 is likewise open and the switch SV2 is alternately opened and closed, the fraction α of the time in which the switch SV2 is closed from the duration of the first switching state a being selected by the control circuit C proportional to the required power of the motor M. As shown by the arrows in the schematic diagram of the motor in state a, current flows on the one hand through the phases U, V and W, V of the motor. All three phases therefore contribute to the space vector U_a of the magnetic field, the contributions of the phases U,V being superposed to a contribution parallel to that of the phase V.

[019] In the following switching state b the switch SU1 is closed with the pulse duty factor α, the switches SV2 and SW2 are open and the switches SU2, SV1, SW1 are open. The phases V, W lie at the low supply voltage and the phase U acquires the high supply potential with the pulse duty factor α. The space vector U_b is turned through 60° in the anticlockwise direction.

[020] In general, in the switching states a, c, e respectively in two phases, the switches connecting to the high supply potential are open and the switches connecting to the low supply potential are closed and in the third phase, the switch connecting to the high supply potential is open and that connecting to the low supply potential is pulsed. There are two different possibilities for a sequence of these three switching states a, c and e; these correspond to the two opposite directions of rotation of the motor. In each interposed switching state b, d or f, in respectively two of the phases U, V , W the switches connecting to the low supply potential are open and those connecting to the high supply potential are open and in the third phase, the switch connecting to the low supply potential is open and that connecting to the high supply potential is pulsed. The pulsed phase is in each case that phase which is pulsed neither in the directly preceding nor in the directly following switching state. Thus, a uniform rotation of the space vector of 60° is obtained from one switching state to the next.

[021] For one phase of the motor, for example, phase U, Fig. 3 shows the result of a calculated simulation of the phase current as a function of time plotted as curve IU together with control signals c_{SU1} and c_{SU2} for the two switches SU1, SU2 supplying the phase U at a load angle δ between the phase

of the control signal c_{SU1} and the electromotive force emf of the motor.

[022]